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Near disappearance of the Angelshark *Squatina squatina* over half a century of observations

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Abstract

Marine extinctions are particularly difficult to detect and almost all have been discovered after the fact. Retrospective analyses are essential to avoid concluding no-extinction when one has occurred. We reconstruct the Angelshark population trajectory in a former hotspot (Wales), using interviews and opportunistic records. After correcting for observation effort and recall bias, we estimate a 70% (1.5%/year) decline in abundance over 46 years. While formerly widespread, Angelshark distribution contracted to a central core of Cardigan Bay. Angelshark declined almost unnoticed in one of the best-monitored and most intensively managed seas in the world. Bycatch may be minimized by limiting netting on shingle reefs in Cardigan Bay. We provide the first quantitative time series to reveal the timing and trajectory of decline of Angelshark in the coastal waters of Wales and uncover historical centers of abundance and remnant populations that provide the first opportunity for the focus of conservation.

KEYWORDS
Elasmobranchii, fisheries, historical ecology, local ecological knowledge, reconstruction of changes in abundance

1 | INTRODUCTION

The abundance of information on target fished species and the absence of data on nontarget species may lead to a biased view of ocean health (Dayton, 1998). Two kinds of mistake might occur depending on the mind-set of the observer (Dulvy & Kindsvater, 2017; Peterman & M'Gonigle, 1992). An evidentiary mind-set aims to avoid falsely assuming that fishing has an effect (equivalent to avoiding a type I error in statistical hypothesis testing). This may lead to the perception that extinctions are unlikely and a low tolerance for false declarations that a species is extinct. A precautionary mind-set assumes that fishing always negatively impacts nontarget species (risking a type II error). The evidentiary mind-set has been dominant in marine conservation, compounded by the difficulties of tracking declines in the ocean.

The reporting of marine extinctions at any scale—local, regional and global—often occurs long after their disappearance (Dulvy, Sadovy, & Reynolds, 2003; Webb & Mindel, 2015). Declines of formerly abundant species can be hard to track because there are few suitable monitoring surveys, and even when there are, they are often optimized for more abundant species and hence may only provide infrequent encounters and unreliable trend estimates (Blanchard, Maxwell, & Jennings, 2007; Maxwell & Jennings, 2005).

Historical ecology, and traditional and local ecological knowledge ("a cumulative body of knowledge, practice and belief evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings with one another and with their environment"; Berkes, Colding, & Folke, 2000; Drew, 2005), are increasingly used to unveil long-term changes and near-baseline ecosystem conditions (Thurstan et al., 2015) For rare organisms, chance reports of sightings or captures often constitute the only source of information that will yield a substantial volume of records (McPherson & Myers, 2009; Smith & Solow, 2011; Solow, 1993). Such sightings are invaluable for assessing declines and extinctions of species, particularly in the marine realm where disappearances typically go undetected for decades. Systematic compilations of opportunistic sightings have been used to document the decline and local extinction of sawfishes (Pristidae) and infer the likely global extinction of the Yangtze River Dolphin (Reis-Filho et al., 2016; Turvey et al., 2010).

The quantitative use of opportunistic observations can be improved by accounting for changes in observation effort (how much time was spent in situations where observations could have been made, McPherson & Myers, 2009) and recall biases (how accurate events are recalled retrospectively, O'Donnell, Pajaro, & Vincent, 2010). The age distribution of the observer population is particularly important because observers cannot report observations from before they began ocean-related activities, such as fishing or diving. They are also more likely to forget observations that were long ago (Daw, Robinson, & Graham, 2011; O'Donnell et al., 2010). Together both processes can create an increasing number of sightings over time when asking people to recall sightings, even when a population is constant or declining.

The Angelshark *Squatina squatina* is a bottom-dwelling (demersal) species formerly found throughout in coastal waters of Northeast Atlantic (Gordon et al., 2017). The combination of their life-history (large body size, late maturity and slow reproduction) and a high catchability in trawl and entanglement-net fisheries underlie the high extinction risk of Squatinidae (Cailliet, Mollet, Pittenger, Bedford, & Natanson, 1992; Dulvy et al., 2014; Fouts & Nelson, 1999). *Squatina squatina* is inferred to have declined steeply throughout its range and in Europe and was initially categorized as Vulnerable in 2000 by IUCN Red List (Ferretti et al., 2015). As understanding of the former abundance and recent absence has come into focus, this species was globally reclassified as Critically Endangered in 2006 (Ferretti et al., 2015; Fortibuoni, Borme, Franceschini, Giovanardi, & Raicevich, 2016; IUCN, 2010).

The coastal seas of Wales, United Kingdom and Ireland appear to be the only locations with regular Angelshark sightings in western Europe, although no Angelsharks have been observed in Ireland since 2011 (Meyers et al., 2017). Designing effective conservation measures for last remaining populations requires an understanding of the population trend and spatial distribution, and an identification of the factors that have been driving their decline (Gordon et al., 2017; Shephard, Wögerbauer, Green, Ellis, & Roche, 2019). Because of their rarity, targeted field surveys in Wales have yet to yield sufficient records to allow calculation of abundance trends. This region is one of the best monitored oceans in the world, nevertheless in NW Europe, only two individual Angelshark were caught in >40 years of trawl surveys (>25,000 hauls, http://www.ices.dk/marine-data/data-portals/Pages/DATRAS.aspx). Further, this area is intensively managed with numerous catch and effort regulations, for mainly target teleost fish species (Fernandes et al., 2017).

Here, we compile reports of captures and sightings of Angelshark to retrospectively document changes in their abundance and distribution in Wales.

2 | METHODS

2.1 | Study area and data sources

We collated records from Wales and the adjacent waters of Cornwall, Devon and Somerset, along the coastlines of the eastern Irish Sea and Bristol Channel since 1880. Here, we report all records spanning 46 years between 1970 and 2016 from Wales and adjacent waters, defined as the area between latitude 51°00′N and 53°45′N. Records were collected from four main data sources: interviews with people that may have encountered Angelshark in recreational and professional activities, logbooks from charter-boats skippers that were identified in these interviews, trophy-catch records and online databases (both scientific and nonscientific, Table 1). Additional context from naturalist books, fisheries catches and scientific research surveys can be found in Bater (2017).

2.1.1 | Interviews

Phone interviews were conducted to collect information on the distribution and abundance of the Angelshark. We used recreational fishing websites, angling forums, social media and exploratory conversations with Bangor University staff to make contact with respondents who were likely to have seen Angelshark (Supporting Information, Table S1). Further interviewees were identified using a snowball sampling procedure whereby each person being interviewed were asked to recommend other people who they thought may have knowledge on records of Angelshark (Goodman, 1961). Although this led to a nonrandom sample, it enhanced collaboration from respondents reducing reticence (e.g., from fearing increased regulations) as well as increasing the chance of encountering those respondents with

TABLE 1 Summary statistics of the data sources of angelshark records

Data source	Subset	Number of data sources	Active years	Earliest record	Latest record	Number of records
Interviews		70	NA	1969	2017	1,184
Charter-boat skipper logbook	Skipper 1	1	1975–2017	1975	2001	518
	Skipper 2	1	1978–1992	1978	1990	52
Trophy catches	NFSA[a]	1	1976–2002	1976	1984	16
	Sea angler	1	1972–2017	1973	2016	60
Online databases		21	NA	1959	2017	30

[a]Overlapping records with Sea Angler magazine removed.
This table reports all records, while subsequent analyses only use records from 1970 to 2016. Most interviewed people did not see any Angelsharks, so therefore the number of datasources is less than the number of interviews done.

relevant information. Respondents were interviewed through a structured questionnaire that contained both open and fixed questions relating to catches and sightings of Angelshark and general information on their history of activities at sea, that is, age; type of fishing practice; fishing gear employed; fishing grounds frequented (Text S1 in Appendix S1). The correct identification of Angelshark compared to Anglerfishes (*Lophius* spp.) was verified by emailing respondents a test set of images.

2.1.2 | Charter-boat skipper logbooks

Through the interviews, we identified two charter-boat skippers that had kept logbooks of all catches. Both reported that they operated in the same area in Cardigan Bay at relatively constant effort over many years (skipper 1: 1975–2017, skipper 2: 1978–1992). Both datasets also included years with zero reported catches.

2.1.3 | Trophy catches

Captures of Angelshark by recreational anglers were extracted from two sources. The National Federation of Sea Anglers (NFSA) annual reports from 1976 to 2002 only include specimens that exceed a species-specific weight threshold (15.9 kg for Angelshark) (Richardson, Kaiser, Edwards-Jones, & Ramsay, 2006). While now defunct, by 2005 the National Federation of Sea Anglers had approximately 40,000 members. The second dataset was obtained from the most popular recreational sea-fishing magazine *Sea Angler*. Any recreational fisher can submit their catch to the magazine, although only the larger specimens tend to be reported (Richardson et al., 2006). However, due to the rarity of the Angelshark, it is likely that most submitted catches will have been published. Both the NFSA and *Sea Angler* datasets were originally compiled by Richardson et al. (2006) and here we updated the *Sea Angler* magazine for the most recent years, completing 541 monthly issues of *Sea Angler* from May 1972 to June 2017. Two common names are in use for *Squatina squatina*, "Angelshark" and "Monkfish," but confusingly monkfish is also used for the morphologically similar Anglerfishes *Lophius* spp. All mentions of "monkfish" in the magazines that could be checked using printed photos were found to be *S. squatina*, and we therefore assumed that all "monkfish" records were *S. squatina*.

2.1.4 | Online databases

A search was conducted to find further records of Angelshark in 23 databases of across two social media platforms (see Table 2 for all sources). We searched online databases first, and then contacted their archivists to check whether we had missed any records in their database, and to see if they held any other sources of information (e.g., books, reports from sightings or specimens). We accessed records from local environmental record centers, local marine wildlife centers and biodiversity databases. We contacted environmental agencies; marine institutions, organizations and societies; national museums; marine and fisheries government divisions; sea fish industry authorities; fishers' associations. We examined recreational catch data published on online sources such as social media and publicly-accessible sea-angling and diving forums (following guidelines of Monkman, Kaiser, & Hyder, 2018). All threads containing predefined search terms ("monkfish," "monk fish," "angel shark," "Angelshark" or "Squatina") were then examined for relevant reports. If no photo was present to confirm the record, the user was contacted to confirm the identification of the species. Records from all available old naturalist books containing descriptions of the species in the United Kingdom dating back to 1881 were compiled by ICES (2016).

2.2 | Graphical and statistical analysis

Missing positions and overlapping records were dealt with as described in Text S2. Only the interview dataset (of mostly commercial and recreational fishers) had

TABLE 2 Databases searched for additional records of Angelshark *Squatina squatina*

Welsh local environmental records Centers
- West Wales Biodiversity Information Centre (WWBIC; www.wwbic.org.uk/en/)
- South East Wales Biodiversity Records Centre (SEWBREC; www.sewbrec.org.uk/)
- North Wales Environmental Information Service (Cofnod; www.cofnod.org.uk/)
- Biodiversity Information Service for Powys & Brecon Beacons National Park (BIS; http://www.b-i-s.org/)

National Biodiversity Network (NBN; https://nbn.org.uk/)
Global Biodiversity Information Facility (GBIF; https://www.gbif.org/)
European Ocean Biogeographic Information System (EurOBIS; www.eurobis.org/)
Marine Biological Association - The Marine Life Information Network (MBA; www.mba.ac.uk/)
The Marine Life Information Network (MarLIN; www.marlin.ac.uk/)
The archive for marine species and habitats data (DASSH; www.dassh.ac.uk/)
Plymouth Marine Laboratories (PML; www.pml.ac.uk/)
Joint Nature Conservation Committee (JNCC; jncc.defra.gov.uk/)
Wildlife Trust Wales (WTW; www.wtwales.org/)
Marine Conservation Society (MCS; https://www.mcsuk.org/)
Cardigan Bay Marine Wildlife Centre (CBMWC; www.cbmwc.org/)
Environmental Agency Rare and Protected Species Records (EARPS; https://registry.nbnatlas.org/)
Welsh Government Marine Fisheries Division (https://www.gov.wales)
Sea Fish Industry Authority (Seafish; www.seafish.co.uk/)
National Museum Wales (NMW; https://museum.wales/)
Natural History Museum (NHM; www.nhm.ac.uk/)
Welsh Federation of Sea Anglers (WFSA; www.wfsa.org.uk/)
Angling forums. Search terms: Monkfish or Monk fish or Angelshark or Angel shark or Squatina
- World Sea Fishing (http://www.worldseafishing.com/)
- Wirral Sea Fishing (http://wirralseafishing.co.uk/)

Diving forum
- Deeperblue (https://forums.deeperblue.com/)

Facebook groups (i.e., South Wales Sea Anglers, Fishing News)
Instagram accounts (i.e., Bristol Channel Fishing, @channel_anglers)

sufficient records to warrant quantitative analysis. Sightings alone can provide a nominal index of abundance over time, but observation effort needs to be accounted for to provide a standardized index of abundance (Barbini, Lucifora, & Figueroa, 2015; McPherson & Myers, 2009). Observation effort of individual respondents could not be directly quantified, instead the period over which they were active was approximated using their age, while also discounting for recall bias of older memories (O'Donnell et al., 2010). The 25th quantile of the age at which they first saw an Angelshark, for the one third of respondents that actually saw an Angelshark, was 19 years, but those respondents are likely to have been active from a younger age than the ones that never saw an Angelshark. Here, we therefore assume that on average respondents were active observers from the age of 19 up to the year of the interview. This means that observation effort accumulated over time as interviewees were not all the same age, and the number of active observers in a year can be used as a proxy for observation effort. Additionally, we assume that for every year further in the past observers fail to recall a further 1% of observations (fraction recalled observations $= 0.99^{[2017 - \text{current year}]}$), meaning that an observer will faithfully recall all Angelshark observed in 2016 but might only recall only 62% of individuals observed in 1970. Our findings are insensitive to the choice of rate of recall bias (Table S2). Observation effort in each year was corrected by multiplication with the rate of recall bias. The standardized, observer-effort corrected, observations-per-unit-effort of Angelshark (sOPUE) was then calculated by dividing the number of observations per year by the recall-bias corrected observation effort. The annual trend in the abundance of sharks was estimated using the Generalized Least Squares regression gls function in the R package nlme (Pinheiro, Bates, DebRoy, & Sarkar, 2013), by fitting the following model: sOPUE ~ year with a first-order autoregressive structure, implemented using corAR1(~year). A GLS was chosen because it allowed fitting a temporal auto-correlation structure.

We also use the complementary approach of McPherson and Myers (2009) to estimate the magnitude of decline of the Angelshark and sensitivity to a range of observation effort scenarios. This model builds on a different set of assumptions and a comparison between the approaches therefore helps us in assessing the robustness of our conclusions. This approach fits a series of generalized linear models using the unstandardized observations from the interviews that provide multiple estimates of declines under alternate scenarios of trends in observation effort relative to a reference period and explicitly addresses uncertainty over observation effort. For more details about the analytical method see McPherson and Myers (2009). We explore scenarios assuming constant observer effort over time, a doubling in observer effort since 1970, and a ninefold increase in observation effort since 1970, as estimated from the analysis of observer ages and probability of recollection explained above.

3 | RESULTS

In total we obtained 1860 Angelshark records, of which more than half were obtained from 172 interviews, and most of the rest from charter-boat skipper log books (Table 1). Of the fishers, 75.9% were recreational anglers. Of the commercial fishers, 14.8% used multiple gears, 6.5% otter trawls, 1.8% gill and trammel nets and 0.9% pots. About two thirds (69%, $n = 828$) the records were supplied by commercial fishers (using a mix of gill and tangle netting, long-lines and otter trawling), while the other third consisted largely of anglers (30.7%, $n = 368$) with four records from divers. The maximum number of sightings by any one fisher was 337. Among those fishers who had caught the species at least once, the average number of sightings was 19.0.

Angelshark persists in Wales but they have declined steeply over the past half century (Figure 1a). The two data sources with a large number of observations reveal a rise in the unstandardized number of records since the 1970s followed by decline in the 2000s, and a possible increase in observations in recent years, and the data sources with fewer records largely support this pattern. The charter-boat logbook from skipper 1 shows a sudden drop in catches from >35 sharks per year up to the late 1990s, to zero reported captures between 2002 and 2016, despite, according the skippers, maintaining a constant and similar activity pattern (Figure 1a).

The percentage of interviewees that had observed Angelshark increased with age from about 50% at age = 20 to 70% at age = 77 (Figure 1b). The age distribution of the respondents resulted in no observers being active prior to 1959, thereafter there was a steep increase in observation effort from 1970 onwards as the number of observers older than 19 years increased, with an approximately 10-fold increase from 1970 to 2016 (Figure 1c). The standardized observations-per-unit-effort revealed a 70% decline over the 46-year span from 1970 to 2016 (1.5% per year, Figure 1d).

Estimates of the magnitude of decline in abundance, from any given reference year to 2016 based on unstandardized observations reported in interviews using the McPherson and Myers (2009) method, also indicate that Angelshark have declined significantly since the 1970s (Figure 2). The magnitude of the decline depends on the assumed change in observation effort. If no trend in observation effort is assumed, the decline in abundance is less than 70% (61–76%). If a 1,000% increase in observation effort since 1970 is assumed (as suggested by Figure 3c), the maximum decline is 97.2% (96.5–97.8%) since 1989.

Angelshark were historically widespread with records returned from all over Wales, but with clear concentrations in Caernarfon Bay, northern Cardigan Bay and Swansea Bay (Figure 3a). The three parallel shingle reefs (called Sarns) in Cardigan Bay exhibited a particular concentration of observations suggesting these may comprise “essential” habitat.

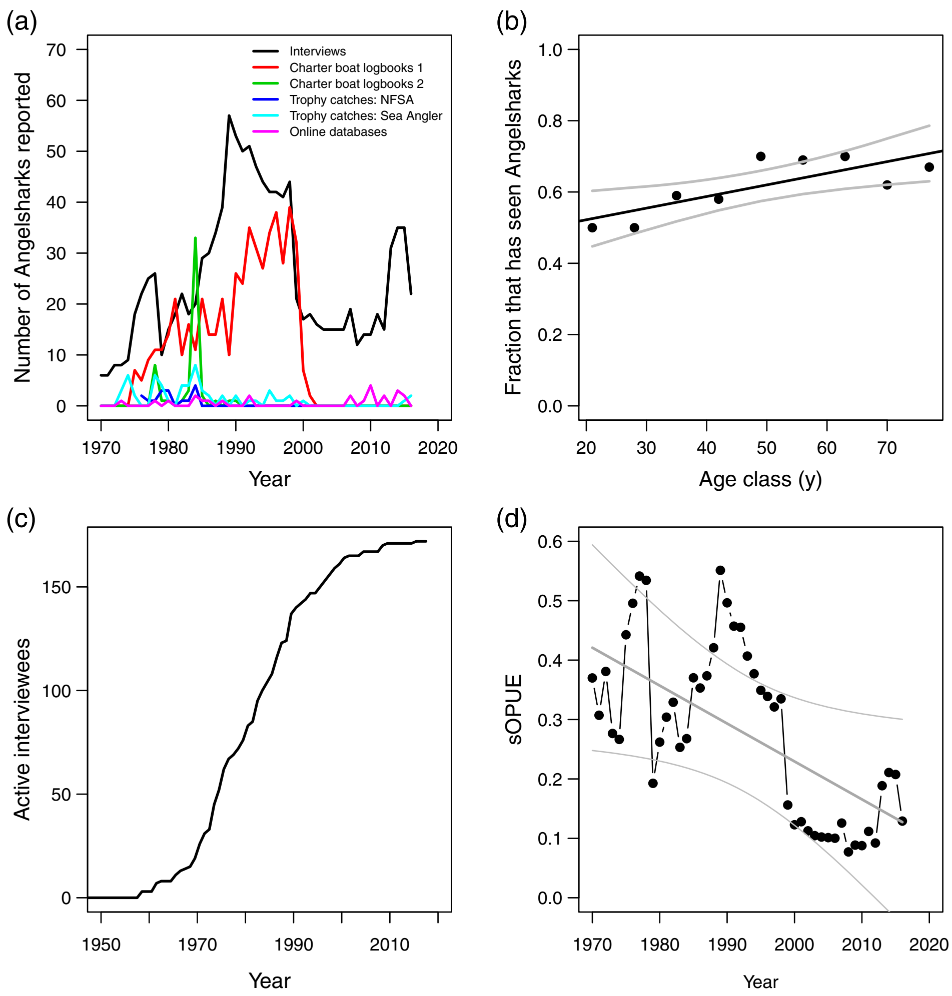

FIGURE 1 Steep decline in Angelshark observations over nearly half a century. (a) Temporal trends in the number of records obtained from six all data sources (see Table 1). (b) The fraction of interviewees that reported seeing Angelshark, fitted line with 95% CI ($F_{1,7} = 10.88$, $R^2 = 0.601$, $p = 0.013$). (c) The reconstructed number of active interviewees in each year based on their ages, assuming they became an active sea user at age = 19 years. (d) Standardized, observer-effort corrected, observations of Angelshark (sOPUE) derived from interviews, $t_{45} = -2.01$, $p = 0.0494$, fitted line with 95% CI plotted. Residuals plotted in Figure S1

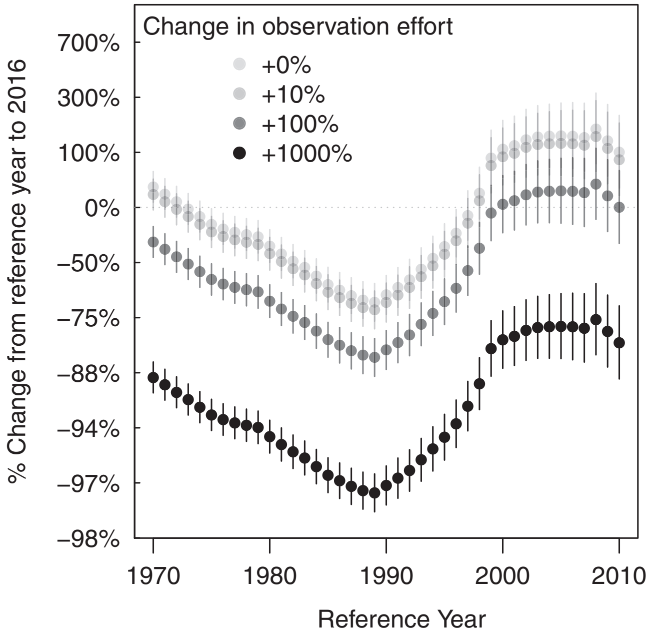

FIGURE 2 Estimates of the magnitude of declines in abundance of Angelshark in Wales, with 95% confidence bounds, between any chosen reference year and 2016, based on observations reported in interviews. Different lines represent different assumed changes in observation effort

Maps show a decade-by-decade contraction of the occupancy over nearly half a century (Figure 3b–f). The decline in records was particularly pronounced in Swansea Bay, which was a hotspot for records from 1970 to 2000 but saw very few sharks after that, and in Caernafon Bay, where no sharks were observed since 2007. As the range contracted to the central core of Cardigan Bay, the fraction of observations there increased from 45% of observations in the 1970s, to 82% in the 2010s.

4 | DISCUSSION

Our study shows that the distribution and abundance of a marine species approaching extinction can be quantified by the careful retrospective analysis of opportunistic records. Although our results are for one marine population in one place only, they have a broader significance. Most importantly, our finding shows that a precautionary mind-set is critical to understanding the true state of the ocean. As time has elapsed, the science community has become convinced that Angelshark were formerly abundant and now rare—rather than naturally rare, even though no new data was becoming available. As the IUCN risk assessment approach allows for suspicion and inference and the use of a precautionary mind-set, the official status of Angelshark has progressively worsened. Now with this new dataset demonstrating steep decline we show that this precautionary thinking has been justified.

These results show that Angelshark persists in Wales despite fivefold decrease in abundance since the 1980s. While formerly widespread in Welsh waters, Angelshark distribution has contracted to a central core of Cardigan Bay. Only interview data yielded a suitable amount of records for a robust quantitative analysis, while records from the other sources corroborated the general pattern indicated by the interview records, and all data sources show a dip in abundance in the 2000–2010 period. The small upturn in records since 2010 may reflect an increase in abundance in response to a halving of multispecies fishing mortality in the EU (Gascuel et al., 2016) (although it is unlikely that this species can increase so quickly in abundance given its life-history), an increased observation effort due to an increase in the amount of time spent by the sea by the public in Wales (Natural Resources Wales, 2015) and further afield (White et al., 2016), or an increased public interest in conservation (O'Bryhim & Parsons, 2015).

The ultimate challenge in the interpretation of opportunistic records is separating true population trends from changes in the observation effort. Because we could not quantify observation effort directly, we made the simplifying assumption that observers were active at a constant effort in space and time. This assumption is likely to have caused some biases in the perceived patterns. The validity of other proxies of observation effort, such as coastal population density, or number of recreational and commercial fishers, could be explored in future studies. Generally, the number of records reported by any individual is too low to suggest that there would have been any incentive to target this rare protected species by anglers and commercial fishers who inevitable must focus on more abundant species. Given the high skew in sightings, with only few people reporting more than half of the sightings it is highly likely that the preferred fishing locations of these few observers might well intersect with areas of preferred Angelsharks habitat. However, we cannot rule out the likelihood that these few individuals were also particularly inclined to document or remember records of these species. Further, we have little sense of whether catchability has changed over time, as fishing and angling gear and practices have changed. Future studies that can quantify the observation effort of respondents in space and time and correct for this are likely to provide more accurate and precise estimates of trends. Only one other paper exists documenting the decline of Angelsharks in two bays in Ireland (Shephard et al., 2019). They only report local numbers of records without correcting for observation effort, and our approach provides an advance as we correct for observation effort and document the contraction of Angelshark distribution in space.

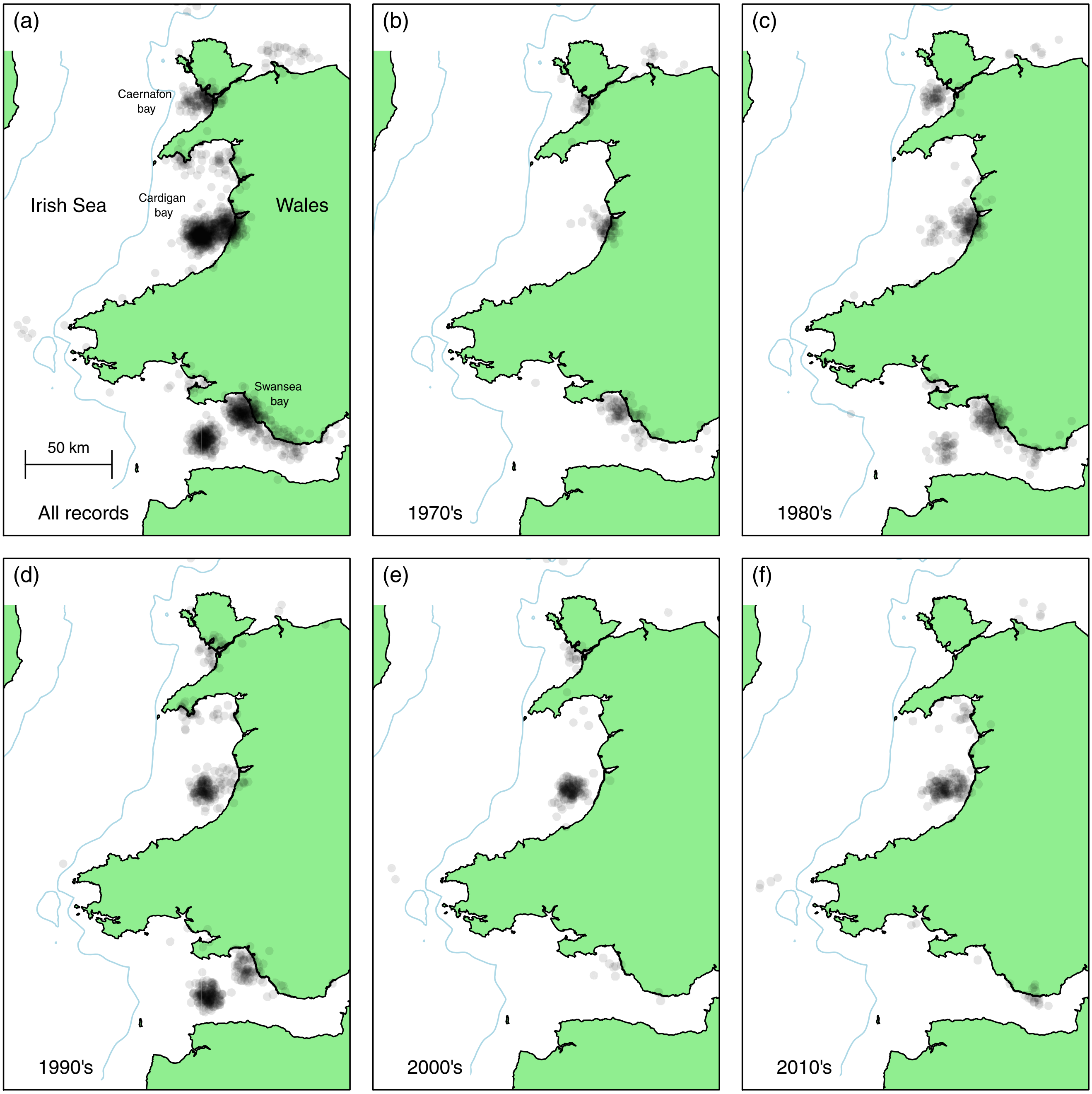

FIGURE 3 (a) The distribution of Angelshark records in Wales from all sources based on reconstructed positions. All records are plotted in transparent grey scale and points are jittered (normal distribution with *SD* = 4,000 m) resulting in some records being on land. This results in the most persistent observation locations being represented by more intense shades and individual isolated locations being represented by single small grey dots. (b–f) Decade-by-decade contraction of the occupancy of Angelshark, over nearly half a century. The 2010 observation period is inevitably truncated comprised of only 6 years of records to 2016. The light blue line is the 50 m depth contour

4.1 | Policy implications

The insights presented here are crucial for improved management and restoration of the Angelshark and their ecosystems. We provide the first data to show that Angelshark are actually present in Wales but have declined steeply, and almost unnoticed, in one of the best-monitored and most intensively managed seas in the world. The availability of graphs of decline is essential to sway the highly evidentiary minds of those involved in marine management. Active conservation is needed to monitor and minimize unintended catches by commercial and recreational fisheries in those areas with the greatest concentrations of observations. It is difficult to attribute the decline to particular causes, but the slow life-history and large size of the Angelshark makes their populations particularly vulnerable to the effects on bycatch in fisheries. The high abundance of Angelshark, as well as that of other sensitive shark and rays species, in the Canary Islands is attributed to the total ban on bottom trawling in 1980 (Barker et al., 2016). Overall bottom trawling effort in coastal waters in Wales is very low compared to other areas (Amoroso et al., 2018) and this may explain why Angelshark have declined less in Wales than in other areas. It is already prohibited to intentionally disturb, target, injure or kill Angelshark within 12 nautical miles of Welsh and English coastlines (Schedule 5 of the Wildlife and Countryside Act 1981), and for commercial fishers it is prohibited to target, retain, tranship or land Angelshark in the EU (Council Regulation [EU] No. 2017/127), so further conservation measures will need to use other approaches. It will be difficult to implement technical modifications to bottom-trawl gears, such as separator grids, without reducing the catches of other flattened species, such as skates (Rajidae) and Anglerfish *Lophius piscatorius*, which together make up >15% by value of Welsh landings (Marine Management Organisation, 2018). Effective conservation of Angelshark in Wales should therefore focus on the avoidance of unintended catches through spatial management by avoiding fishing at locations with known concentrations of Angelshark, such as northern Cardigan Bay. This area is already protected as a Special Area of Conservation (SAC), but is important for and allows recreational (mostly angling) and commercial fishing (drift and set gill and tangle netting, and some trawling) (Natural Resources Wales, 2017). The three parallel shingle reefs (Sarns) with high and recent concentrations of Angelshark records fall within this SAC, and restrictions to limit netting on these are likely to be the most effective way to reduce unintended bycatch.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

JGH initiated and designed the study. RB and DG carried out the data collection. JH and NKD carried out the majority of the data analysis and writing, with all other authors contributing.

DATA ACCESSIBILITY

Due to possible sensitivity of human subjects' data, and in line with the ethical approval and the agreement with the interviewees, raw data files are only accessible to the authors. A simplified version of the data with all sensitive information removed is available in Table S3.

ETHICS STATEMENT

The research received ethical approval from the Bangor university ethics committee.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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